

DESCRIPTION

IONIC LIQUID, METHOD FOR PRODUCING SAME, DOUBLE LAYER CAPACITOR
COMPRISING SAME, AND LITHIUM BATTERY

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TECHNICAL FIELD

The present invention relates to ionic liquids, and more particularly to ionic liquids with low viscosities and melting points as well as high conductivities and electrochemical stabilities. The present invention also relates to a method of producing ionic liquids as well as lithium batteries (for example, lithium-ion batteries, lithium primary batteries and lithium secondary batteries, and particularly lithium secondary batteries) and electric double-layer capacitors comprising the ionic liquids.

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PRIOR ART

Ionic liquids have attracted special attention for the past several years, owing to their potential for application as the electrolytes, reaction media and catalysts for organic syntheses for a variety of electrochemical devices, such as lithium secondary batteries, solar cells, actuators, electric double-layer capacitors and the like. Compared with conventional organic liquid electrolytes, ionic liquids as such electrolytes have the main advantages of flame retardancy, non-volatility and high thermal stability. Bistrifluoromethylsulfonylimide ($[(CF_3SO_2)_2N]^-$) and tetrafluoroborate (BF_4^-) have attracted attention as anions for most of the ionic liquids so far reported, because of their high electrochemical stabilities and thermal stabilities (Patent Publications 1 and 2).

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However, ionic liquids containing these anions suffer from problems such as low conductivity at low temperature, in particular.

Patent Publication 3 discloses boron compounds; however, for example, triethylmethyammonium- CF_3BF_3 manufactured in the Examples has a high melting point of 181 °C, and therefore cannot

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serve as an ionic liquid.

Further, Patent Publication 4 discloses the BF_3CF_3 salt of 1-ethyl-3-methylimidazolium in Example 1.

[Patent Publication 1] Japanese Unexamined Patent
5 Publication No. 2002-099001

[Patent Publication 2] Japanese Unexamined Patent
Publication No. 2003-331918

[Patent Publication 3] Japanese Unexamined Patent
Publication No. 2002-63934

10 [Patent Publication 4] Japanese Unexamined Patent
Publication No. 2004-123631

DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

15 An object of the present invention is to provide ionic liquids with low viscosities, low melting points and high conductivities by improving the anionic and cationic components. The present invention also relates to electric double-layer capacitors and lithium batteries comprising such ionic liquids,
20 especially to lithium secondary batteries.

Means for Solving the Problems

In view of the aforementioned problems, the present inventors conducted extensive research, and found that an ionic
25 liquid with a low viscosity and low melting point as well as high conductivity at low temperatures can be obtained using at least one anion represented by $[\text{BF}_3(\text{C}_n\text{F}_{2n+1})]^-$ where n represents 1, 2, 3 or 4, or using such an anion together with a salt containing a particular aliphatic or heterocyclic ammonium-based cation.

30 The present invention provides ionic liquids and a production method therefor as well as electric double-layer capacitors and lithium batteries using such ionic liquids, as itemized below:

1. An ionic liquid comprising:
35 at least one anion represented by $[\text{BF}_3(\text{C}_n\text{F}_{2n+1})]^-$ wherein

n represents 1, 2, 3 or 4; and

at least one organic ammonium ion represented by general formula (I):



5 wherein R^1 to R^4 are the same or different, each representing an alkyl, fluoroalkyl, alkoxy, polyether, or alkoxyalkyl group, or R^1 and R^2 taken together with the nitrogen atom may form a pyrrolidine, piperidine, or morpholine ring; provided that R^1 to R^4 satisfy the conditions (i) through (iii) shown below:

(i) when R^1 and R^2 taken together with the nitrogen atom form a pyrrolidine, piperidine, or morpholine ring, either R^3 or R^4 is an alkyl group with 3 or more carbon atoms or alkoxyalkyl group;

15 (ii) when R^1 and R^2 do not form a pyrrolidine, piperidine or morpholine ring, at least one of R^1 to R^4 is an alkoxy, polyether or alkoxyalkyl group; and

(iii) when R^1 to R^3 are the same or different, each being methyl or ethyl, R^4 is a C_{3-10} linear or branched alkyl group.

20 2. An ionic liquid according to item 1, wherein the anion is at least one member selected from the group consisting of $[\text{BF}_3(\text{CF}_3)]^-$, $[\text{BF}_3(\text{C}_2\text{F}_5)]^-$ and $[\text{BF}_3(\text{C}_3\text{F}_7)]^-$.

25 3. An ionic liquid according to item 1, wherein R^1 , R^2 and R^3 are the same or different, each representing an alkyl group, and R^4 represents an alkoxyalkyl group.

4. An ionic liquid according to item 1, wherein R^1 and R^2 taken together with the nitrogen atom form a pyrrolidine, piperidine or morpholine ring; R^3 is methyl or ethyl; and R^4 is an alkyl group with 3 or more carbon atoms or alkoxyalkyl group.

30 5. An ionic liquid according to item 1, wherein R^1 and R^2 taken together with the nitrogen atom form a pyrrolidine, piperidine or morpholine ring; R^3 is methyl; and R^4 is an alkyl group with 3 or more carbon atoms or alkoxyalkyl group.

35 6. An ionic liquid according to item 1, wherein R^1 and R^2 taken together with the nitrogen atom form a pyrrolidine ring;

R^3 is methyl; and R^4 is an alkyl group with 3 or more carbon atoms or alkoxyalkyl group.

7. An electric double-layer capacitor comprising the ionic liquid according to item 1.

5 8. A lithium battery comprising the ionic liquid according to item 1.

9. A method of producing an ionic liquid comprising mixing a compound containing as an anionic component at least one anion represented by $[BF_3(C_nF_{2n+1})]^-$ wherein n represents 1, 2, 3 or 10 4 with a compound containing as a cationic component at least one organic ammonium ion represented by general formula (I):



wherein R^1 to R^4 are the same or different, each representing an alkyl, fluoroalkyl, alkoxy, polyether, or 15 alkoxyalkyl group, or R^1 and R^2 taken together with the nitrogen atom may form a pyrrolidine, piperidine, or morpholine ring; provided that R^1 to R^4 satisfy the conditions (i) through (iii) shown below:

(i) when R^1 and R^2 taken together with the nitrogen 20 atom form a pyrrolidine, piperidine, or morpholine ring, either R^3 or R^4 is an alkyl group with 3 or more carbon atoms or alkoxyalkyl group;

(ii) when R^1 and R^2 do not form a pyrrolidine, piperidine or morpholine ring, at least one of R^1 to R^4 is an 25 alkoxy, polyether or alkoxyalkyl group; and

(iii) when R^1 to R^3 are the same or different, each being methyl or ethyl, R^4 is a C_{3-10} linear or branched alkyl group.

EFFECTS OF THE INVENTION

30 The present invention provides ionic liquids with low viscosities and melting points.

Ionic liquids of the present invention are especially suitable for use in lithium batteries and electric double-layer capacitors. The ionic liquids are also useful in solar cells, 35 electrochemical sensor devices, electrochemical (electrochromic)

display devices, and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a linear sweep voltammogram of ionic liquids measured on a glassy carbon electrode (surface area: $7.85 \times 10^{-3} \text{ cm}^2$) at the first sweep, wherein the sweep rate is 50 m Vs^{-1} ; the counter electrode is a Pt wire; the reference electrode is a platinum wire immersed in EMI-TFSI ionic liquid containing 15 mM iodine and 60 mM tetrapropylammonium iodide dissolved therein in a glass cylinder having its end capped with a glass filter; and the potential (V) for use as the potential reference is the redox potential of the ferrocene (Fc)/ferrocenium (Fc⁺) redox couple that can be observed when ferrocene is dissolved in each ionic liquid; and

Fig. 2 shows results of linear sweep voltammetry.

BEST MODE FOR CARRYING OUT THE INVENTION

Ionic liquids for use in the present invention typically have melting points of 150°C or less, preferably 80°C or less, more preferably 60°C or less, still more preferably 40°C or less, and even more preferably 25°C or less. For example, ionic liquids with melting points of 150°C or less can be widely used in fuel cells. Ionic liquids for use in energy devices such as solar cells, lithium batteries, capacitors, etc., and electrochemical devices such as electrochromic devices, electrochemical sensors, etc. preferably have melting points of room temperature (25°C) or less, and more preferably 0°C or less.

The anionic component of the ionic liquid for use in the present invention is at least one member selected from the group consisting of $\text{BF}_3(\text{CF}_3)^-$, $[\text{BF}_3(\text{C}_2\text{F}_5)]^-$, $[\text{BF}_3(\text{C}_3\text{F}_7)]^-$ (i.e., $[\text{BF}_3(\text{n-C}_3\text{F}_7)]^-$ and $[\text{BF}_3(\text{i-C}_3\text{F}_7)]^-$), and $[\text{BF}_3(\text{C}_4\text{F}_9)]^-$ (i.e., $[\text{BF}_3(\text{n-C}_4\text{F}_9)]^-$, $[\text{BF}_3(\text{i-C}_4\text{F}_9)]^-$, $[\text{BF}_3(\text{sec-C}_4\text{F}_9)]^-$, and $[\text{BF}_3(\text{tert-C}_4\text{F}_9)]^-$); and preferably at least one member selected from the group consisting of $[\text{BF}_3(\text{CF}_3)]^-$, $[\text{BF}_3(\text{C}_2\text{F}_5)]^-$, and $[\text{BF}_3(\text{C}_3\text{F}_7)]^-$ (i.e., $[\text{BF}_3(\text{n-C}_3\text{F}_7)]^-$ and $[\text{BF}_3(\text{i-C}_3\text{F}_7)]^-$); and more preferably $[\text{BF}_3(\text{CF}_3)]^-$ and/or

[BF₃(C₂F₅)]⁻. The above-mentioned anions are known compounds, and are described in, for example, G. A. Molander, B. J. Hoag, *Organometallics*, 22, (2003), 3313; and Zhi-Bin Zhou, Masayuki Takeda, Makoto Ue, *J. Fluorine. Chem.*, 123 (2003) 127. The ionic
 5 liquid of the present invention may comprise a single anionic component, or two or more anionic components to further decrease the melting point.

The ionic liquid can be produced by mixing an organic ammonium compound with a salt of at least one anionic component
 10 represented by [BF₃(C_nF_{2n+1})]⁻ wherein n represents 1, 2, 3 or 4 and a cationic component, such as an alkali metal ion (Na⁺, K⁺, Li⁺, Cs⁺, etc.), an alkaline-earth metal ion (Ca²⁺, Mg²⁺, Ba²⁺, etc.), or H⁺, Bu₃Sn⁺, or the like; and separating an ionic liquid consisting of the organic ammonium ion and [BF₃(C_nF_{2n+1})]⁻ wherein n represents
 15 1, 2, 3, or 4, or [BF₃(CF=CF₂)]⁻. For example, an ionic liquid consisting of [BF₃(C_nF_{2n+1})]⁻ wherein n represents 1, 2, 3, or 4 and an organic ammonium ion can be preferably obtained by mixing an (organic ammonium)⁺(OH)⁻ salt with a [BF₃(C_nF_(2n+1))]⁻H⁺ salt, wherein n represents 1, 2, 3, or 4, which is prepared by passing through
 20 an ion exchange resin; and removing water. A salt exchange reaction for obtaining an ionic liquid can be carried out by solvent extraction when the desired molten salt is capable of being extracted.

Although a single organic ammonium ion may be used, a
 25 combination of two or more organic ammonium ions allows the melting point and viscosity of the ionic liquid to be further decreased.

The anion(s) of the ionic liquid used is at least one member selected from the group consisting of anions represented
 30 by [BF₃(C_nF_{2n+1})]⁻ wherein n represents 1, 2, 3, or 4, such an anion being the primary component; however, other anions may also be added so long as the resulting salt is an ionic liquid.

Examples of organic ammonium compounds include salts of organic ammonium cations with hydroxide (OH⁻), halogen, nitrate,
 35 sulfate, phosphate, perchlorate, methanesulfonate,

toluenesulfonate ions, and the like.

The ionic liquid may also be produced using at least one anion selected from the group represented by $[\text{BF}_3(\text{C}_n\text{F}_{2n+1})]^-$ wherein n represents 1, 2, 3 or 4 in the form of, e.g., silver, calcium, barium and/or the like salts, together with an organic ammonium ion, in the form of, e.g., a halide salt, sulfate salt or the like, to form a sparingly soluble salt, such as a silver halide, barium sulfate, calcium sulfate or the like resulting from aforementioned counterions, and removing the formed salt.

Alternatively, the ionic liquid may be prepared by mixing (organic ammonium(s) of general formula $(\text{I})^+(\text{OH})^-$ with at least one member selected from the group consisting of anions represented by $[\text{BF}_3(\text{C}_n\text{F}_{2n+1})]^- \text{H}^+$ wherein n represents 1, 2, 3, or 4.

Examples of alkyl groups include C_{1-20} , preferably C_{1-10} , more preferably C_{1-6} , and still more preferably C_{1-3} linear or branched alkyl groups, such as methyl, ethyl, n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl, t-butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, hexadecyl, octadecyl, eicosyl, and the like.

Examples of fluoroalkyl groups include C_{1-20} , preferably C_{1-10} , more preferably C_{1-6} , and still more preferably C_{1-3} polyfluoroalkyl and perfluoroalkyl groups wherein at least one of the hydrogen atoms of an above-mentioned alkyl group is substituted with fluorine.

Examples of alkoxy groups include C_{1-20} , preferably C_{1-10} , more preferably C_{1-6} , and still more preferably C_{1-3} linear or branched alkoxy groups, wherein an aforementioned alkyl group is attached to oxygen.

The alkoxy and alkyl groups of alkoxyalkyl groups are the same as mentioned above. Examples of alkoxyalkyl groups include C_{1-20} , preferably C_{1-10} , more preferably C_{1-6} , and still more preferably C_{1-3} linear or branched alkyl groups substituted with C_{1-20} , preferably C_{1-10} , more preferably C_{1-6} , and still more preferably C_{1-3} linear or branched alkoxy groups; such as, preferably $-(\text{C}_{1-3} \text{ alkylene})-\text{O}-(\text{C}_{1-3} \text{ alkyl})$; and more preferably

methoxymethyl (CH_2OCH_3), methoxyethyl ($\text{CH}_2\text{CH}_2\text{OCH}_3$), ethoxymethyl ($\text{CH}_2\text{OCH}_2\text{CH}_3$), ethoxyethyl ($\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_3$), methoxypropyl ($\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_3$), ethoxypropyl ($\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_3$), propoxymethyl ($\text{CH}_2\text{OCH}_2\text{CH}_2\text{CH}_3$), propoxyethyl ($\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_2\text{CH}_3$), isopropoxymethyl ($\text{CH}_2\text{OCH}(\text{CH}_3)_2$), and isopropoxyethyl ($\text{CH}_2\text{CH}_2\text{OCH}(\text{CH}_3)_2$) groups; and most preferably methoxymethyl (CH_2OCH_3), methoxyethyl ($\text{CH}_2\text{CH}_2\text{OCH}_3$), ethoxymethyl ($\text{CH}_2\text{OCH}_2\text{CH}_3$), and ethoxyethyl ($\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_3$) groups.

Examples of polyether groups include those represented by $-(\text{CH}_2)_{n1}-\text{O}-(\text{CH}_2\text{CH}_2\text{O})_{n2}-(\text{C}_{1-4} \text{ alkyl})$; $-(\text{CH}_2)_{n1}-\text{O}-(\text{CH}_2\text{CH}(\text{CH}_3)\text{O})_{n2}-(\text{C}_{1-4} \text{ alkyl})$; or $-(\text{CH}_2)_{n1}-\text{O}-(\text{CH}(\text{CH}_3)\text{CH}_2\text{O})_{n2}-(\text{C}_{1-4} \text{ alkyl})$, where $n1$ is an integer from 1 to 4; $n2$ is an integer from 1 to 4; and the C_{1-4} alkyl is, for example, methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, tert-butyl, or the like.

Alkenyl groups or the aforementioned alkyl groups may have one or more of $-\text{O}-$, $-\text{COO}-$ and $-\text{CO}-$ interposed between C-C single bonds at any positions to form ether, ester, or ketone structures.

Examples of alkyl groups with 3 or more carbon atoms attached to a pyrrolidine, piperidine, or morpholine ring include C_{3-20} , preferably C_{3-10} , and more preferably C_{3-7} linear or branched alkyl groups, such as n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl, t-butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, hexadecyl, octadecyl, eicosyl, and the like.

Examples of C_{3-10} alkyl groups represented by R^4 are C_{3-10} , preferably C_{4-8} , and more preferably C_{4-6} linear or branched alkyl groups, such as n-propyl, isopropyl, n-butyl, sec-butyl, isobutyl, t-butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, hexadecyl, octadecyl, eicosyl, and the like.

R^1 and R^2 taken together with the nitrogen atom to which they are attached may form pyrrolidinium, piperidinium or morpholinium.

Examples of preferable ammonium ions, wherein R^1 , R^2 and R^3 are the same or different, each being methyl or ethyl, and

wherein R^4 is a C_{3-10} linear or branched alkyl group, include methyldiethyl(n-, i-, sec-, or tert-)butylammonium (N_{1224}), dimethylethyl(n-, i-, sec-, or tert-)butylammonium (N_{1124}), trimethyl(n-, i-, sec-, or tert-)butylammonium (N_{1114}), triethyl(n-,
 5 i-, sec-, or tert-)butylammonium (N_{2224}), methyldiethylhexylammonium (N_{1226}), dimethylethylhexylammonium (N_{1126}), trimethylhexylammonium (N_{1116}), and triethylhexylammonium (N_{2226}).

Examples of organic ammonium ions which can be suitably
 10 used in the present invention are illustrated below:

[Table 1]

R^1	R^2	R^3	R^4
same or different, each being methyl or ethyl			C^{3-10} alkyl
alkyl	alkyl	alkyl	alkoxyalkyl
alkyl	alkyl	alkyl	polyether
Pyrrolidine ring		alkyl	alkoxyalkyl
Pyrrolidine ring		alkyl	C_3 or more alkyl
Pyrrolidine ring		alkyl	polyether
Pyrrolidine ring		alkyl	alkoxyalkyl
Pyrrolidine ring		alkyl	C_3 or more alkyl
Pyrrolidine ring		alkyl	polyether
morpholine ring		alkyl	alkoxyalkyl
morpholine ring		alkyl	C_3 or more alkyl
morpholine ring		alkyl	polyether

Particularly preferable cations in the present
 15 invention which are shown by Table 1 and substituted with a lower alkyl group on the nitrogen atom are listed below:

(1) R^1 to R^3 are the same or different, each being methyl or ethyl, and R^4 is a C^{3-10} alkyl;

(2) R^1 to R^3 are the same or different, each being a C_{1-4} alkyl group, and R^4 is $-(C_{1-3} \text{ alkylene})-O-(C_{1-3} \text{ alkyl})$;
 20

(3) R^1 and R^2 taken together with the nitrogen atom form a pyrrolidine, piperidine, or morpholine ring; R^3 is methyl or ethyl; and R^4 is a C_{1-3} alkoxy C_{1-3} alkyl; and

(4) R^1 and R^2 taken together with the nitrogen atom
 25 form a pyrrolidine, piperidine, or morpholine ring; R^3 is methyl

or ethyl; and R^4 is a C_{3-8} alkyl.

Ionic liquids of the present invention are capable of easily dissolving electrolytes such as lithium salts, and are also incombustible and have low viscosities. Therefore, the ionic liquids can be suitably used as electrolyte solvents for lithium batteries such as lithium secondary batteries, electric double-layer capacitors, solar cells, electrochemical sensor devices, electrochemical (electrochromic) display devices and the like.

[Examples]

The present invention is described in further detail below with reference to the Examples.

Reference Example 1: Anion Synthesis

$K[CF_3BF_3]$ was prepared in the manner as described in G. A. Molander, B. J. Hoag, *Organometallics*, 22, (2003), 3313, and then the $K[CF_3BF_3]$ was subjected to a cation exchange process as described in S. Mori, K. Ida, and M. Ue, US Pat. 4, 892, 944 (1990), thereby yielding aqueous $H_{solv}.[CF_3BF_3]_{solv}$.

$K[C_2F_5BF_3]$, $K[n-C_3F_7BF_3]$ and $K[n-C_4F_9BF_3]$ were prepared in the manner as described in Zhi-Bin Zhou, Masayuki Takeda, Makoto Ue, *J. Fluorine. Chem*, 123 (2003) 127, and then the $K[C_2F_5BF_3]$, $K[n-C_3F_7BF_3]$ and $K[n-C_4F_9BF_3]$ were each subjected to a cation exchange process as described in S. Mori, K. Ida, and M. Ue, US Pat. 4, 892, 944. (1990), thereby yielding aqueous $solv[n-C_2F_5BF_3]_{solv}$, $H_{solv}[n-C_3F_7BF_3]_{solv}$ and $H_{solv}[n-C_4F_9BF_3]_{solv}$, respectively.

Reference Example 2: Cation Synthesis

(1) Synthesis of diethylmethoxymethylammonium chloride ($C3: N_{102122}^+Cl^-$)

An amine (diethylmethylaniline) and an equimolar amount of a halogen-substituted ether compound (methoxyethylchloride) as starting materials were mixed in acetonitrile, and then the mixture was reacted for 12 to 72 hours by heating in an autoclave under mild conditions. After the reaction, the quaternary ammonium salt product was recrystallized in an appropriate solvent, and the formation of diethylmethoxymethylammonium chloride ($N_{102122}^+Cl^-$) was confirmed by NMR.

The halide thus obtained was converted to the hydroxide ($N_{102122}^+OH^-$) with an anion exchange resin.

(2) Synthesis of trimethylmethoxyethylammonium bromide (C1: $N_{102111}^+Br^-$); dimethylethylmethoxyethylammonium bromide (C2: $N_{102112}^+Br^-$); and triethylmethoxyethylammonium bromide (C4: $N_{102222}^+Br^-$)

$CH_3OCH_2CH_2Br$ and an equimolar amount of an amine (one each of triethylamine, dimethylethylamine or triethylamine) as starting materials were mixed in anhydrous acetone, and then each mixture was reacted for 12 to 72 hours by heating in an autoclave under mild conditions. After the reaction, each quaternary ammonium salt product was recrystallized in acetone, and the formation of trimethylmethoxyethylammonium bromide ($N_{102111}^+Br^-$), dimethylethylmethoxyethylammonium bromide ($N_{102112}^+Br^-$) and triethylmethoxyethylammonium bromide ($N_{102222}^+Br^-$) was confirmed by NMR.

The bromides thus obtained were converted to the hydroxides ($N_{102111}^+OH^-$, $N_{102112}^+OH^-$ and $N_{102222}^+OH^-$, respectively) with an anion exchange resin.

(3) Synthesis of methylmethoxyethylpiperidinium bromide (C5: $Pi_{102.1}^+Br^-$); methylmethoxyethylpyrrolidinium bromide (C6: $Py_{102.1}^+Br^-$); ethyldimethylmethoxymethylammonium bromide (C7: $N_{102.112}^+Br^-$); butyldimethylmethylanmonium bromide (C8: $N_{1224}^+Br^-$); methylmethoxymethylpyrrolidinium bromide (C9: $Py_{101.1}^+Br^-$); methylbutylmorpholinium bromide (C10: $Mor_{14}^+Br^-$); and methylmethoxyethylmorpholinium bromide (C11: $Mor_{1.102}^+Br^-$)

C5 ($Pi_{102.1}^+Br^-$), C6 ($Py_{102.1}^+Br^-$) and C11 ($Mor_{1.102}^+Br^-$) were synthesized in a similar manner as in synthesis (2) above, except for using N-methylpyrrolidine, N-methylpiperidine and N-methylmorpholine instead of the amines (triethylamine, dimethylethyl amine and triethylamine).

In addition, C7 ($N_{102.112}^+Br^-$), C8 ($N_{1224}^+Br^-$), C9 ($Py_{101.1}^+Br^-$) and C10 ($Mor_{14}^+Br^-$) were synthesized in a similar manner as in synthesis (2) above, except for using dimethylethylamine, methyldiethylamine, methylpyrrolidine or N-

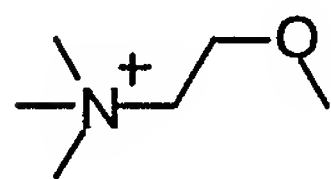
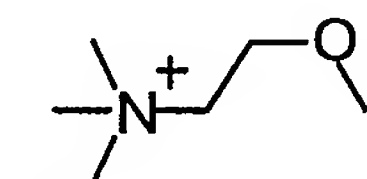
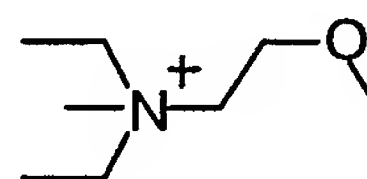
methyldmorpholine as the amine; and using $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$ or $\text{CH}_3\text{OCH}_2\text{Br}$ as the bromide.

The bromides thus obtained were converted to the hydroxides (C5: $\text{Pi}_{102.1}^+\text{OH}^-$; C6: $\text{Py}_{102.1}^+\text{OH}^-$; C7: $\text{N}_{102.112}^+\text{OH}^-$; C8: $\text{N}_{1224}^+\text{OH}^-$; C9: $\text{Py}_{101.1}^+\text{OH}^-$; C10: $\text{Mor}_{14}^+\text{OH}^-$; and C11: $\text{Mor}_{1.102}^+\text{OH}^-$, respectively) with an anion exchange resin.

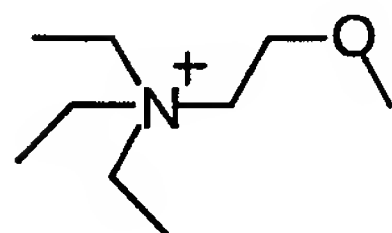
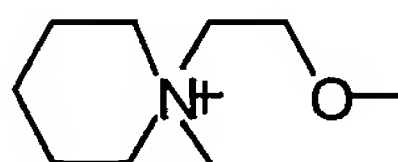
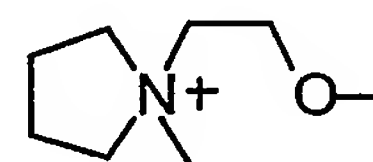
The structural formulae of ammonium ions C1 through C11 are shown below:

[Formulae 1]

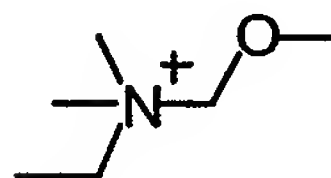
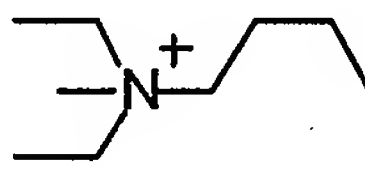
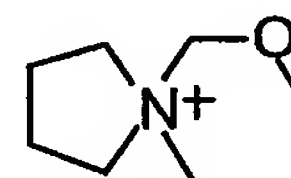
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C1 ($\text{N}_{102.111}$)C2 ($\text{N}_{102.112}$)C3 ($\text{N}_{102.122}$)

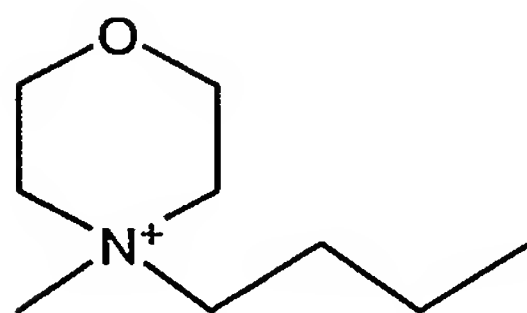
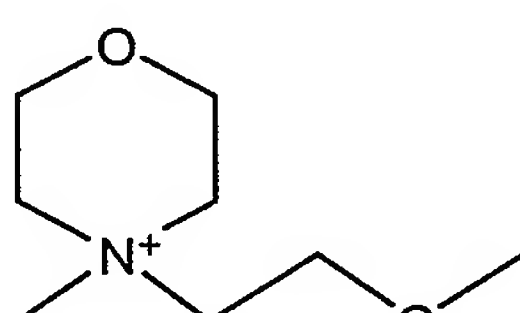
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C4 ($\text{N}_{102.222}$)C5 ($\text{Pi}_{102.1}$)C6 ($\text{Py}_{102.1}$)

20

C7 ($\text{N}_{102.112}$)C8 (N_{1224})C9 ($\text{Py}_{101.1}$)

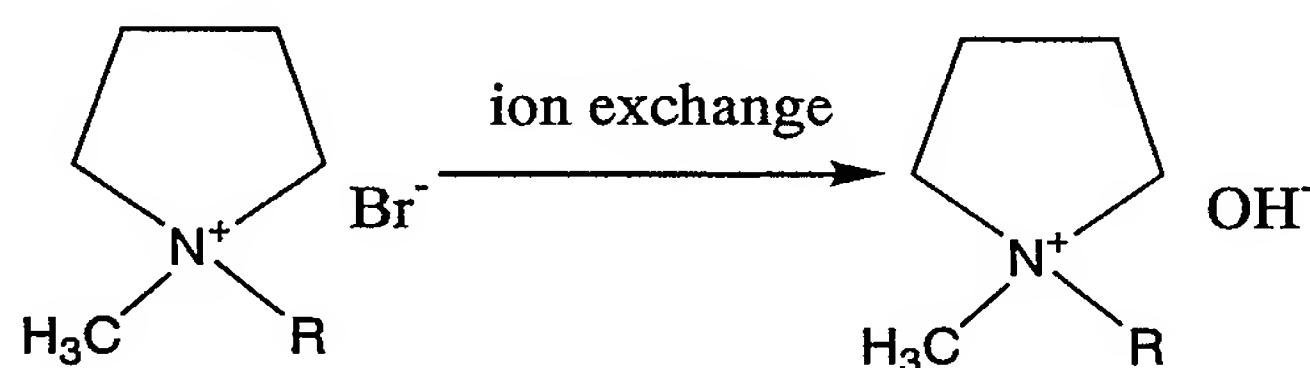
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C10(Mor_{14})C11($\text{Mor}_{1.102}$)

(4) Synthesis of pyrrolidine-based quaternary ammonium salts

Cations shown below were synthesized in a similar manner as in synthesis (2), except for using N-methylpyrrolidine instead of the amines (triethylamine, dimethylethyl amine and triethylamine), and using $\text{CH}_3(\text{CH}_2)_p\text{Br}$ where p is an integer from 0 to 6, $\text{CH}_3\text{OCH}_2\text{Br}$, $\text{CH}_3\text{OCH}_2\text{CH}_2\text{Br}$, $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_2\text{Br}$, or $\text{CH}_3\text{O}(\text{CH}_2\text{CH}_2)_2\text{OCH}_2\text{CH}_2\text{Br}$ as the bromide, and the bromides obtained were then converted to the hydroxides with an anion exchange resin. The cations are shown below along with their abbreviations:

[Table 2]



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R	Cation	R	Cation
CH_3	Py ₁₁	$n\text{-C}_6\text{H}_{13}$	Py ₁₆
C_2H_5	Py ₁₂	$n\text{-C}_7\text{H}_{15}$	Py ₁₇
$n\text{-C}_3\text{H}_7$	Py ₁₃	$\text{C}_2\text{H}_5\text{O}(\text{CH}_2)_2$	Py _{1.202}
$n\text{-C}_4\text{H}_9$	Py ₁₄	$\text{CH}_3\text{O}(\text{CH}_2)\text{O}(\text{CH}_2)_2$	Py _{1.10202}
$n\text{-C}_5\text{H}_{11}$	Py ₁₅		

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(5) Known ammonium compounds

In addition to the above, methyltriethylammonium hydroxide ($\text{N}_{1222}\cdot\text{OH}^-$) and tetraethylammonium hydroxide ($\text{N}_{2222}\cdot\text{OH}^-$) were prepared by a known process.

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Example 1: Preparation of Ionic Liquids

An aqueous solution (50 mmol) of any one of the anions ($\text{H}_{\text{solv}}[\text{CF}_3\text{BF}_3]_{\text{solv}}$, $\text{H}_{\text{solv}}[n\text{-C}_2\text{F}_5\text{BF}_3]_{\text{solv}}$, $\text{H}_{\text{solv}}[n\text{-C}_3\text{F}_7\text{BF}_3]_{\text{solv}}$ and $\text{H}_{\text{solv}}[n\text{-C}_4\text{F}_9\text{BF}_3]_{\text{solv}}$) obtained in Reference Example 1 was filtered before use, and then the filtrate was neutralized by an equimolar amount of any one of the hydroxides of ammonium cations obtained in

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Reference Example 2. The ionic liquid was concentrated to about 20 ml under reduced pressure at 30 to 40 °C, and then the bottom layer was separated, followed by washing with deionized water (10 ml) and toluene (20 ml × 2). The resulting ionic liquid bottom layer was dried under vacuum (0.03 mmHg) at 60 °C for 12 hours, so as to yield the target ionic liquid.

Tables 3 to 5 below show the combinations of the anions and cations along with their physical values.

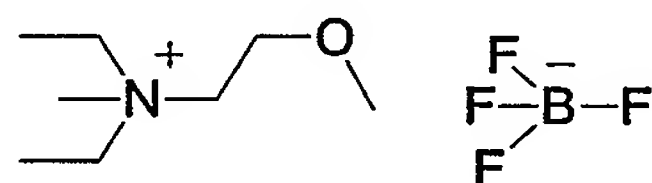
In addition, data such as NMR (^1H , ^{11}B and ^{19}F), elemental analysis and the like on some of the ionic liquids obtained are presented below:

$\text{N}_{102.122}[\text{BF}_4]$

^1H NMR (399.65 MHz/acetone- d_6 , δ ppm relative to internal TMS): 1.39 (t, $J = 7.2\text{Hz}$, NCH_2CH_3), 3.18 (s, NCH_3), 3.38 (s, OCH_3), 3.58 (q, $J = 7.3\text{Hz}$, NCH_2CH_3), 3.67 (t, $J = 4.8\text{Hz}$, $\text{OCH}_2\text{CH}_2\text{N}$), 3.88 (s, $\text{OCH}_2\text{CH}_2\text{N}$).

Anal. Calc. for $\text{C}_8\text{H}_{20}\text{BF}_4\text{NO}$: C, 41.2; H, 8.7; N, 6.0. Found: C, 41.3; H, 8.5; N, 5.9%.

[Chemical Formula 2]



$\text{N}_{102.122}[\text{n-C}_2\text{F}_5\text{BF}_3]$

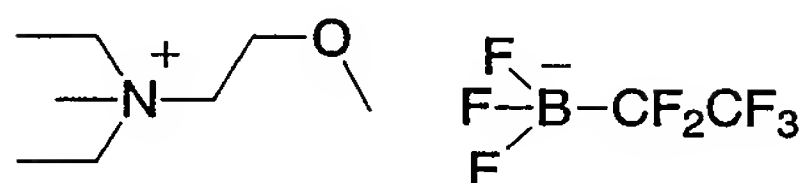
^1H NMR: (399.65 MHz/acetone- d_6 , δ ppm relative to internal TMS): 1.41 (t, $J = 7.2\text{ Hz}$, NCH_2CH_3), 3.19 (s, NCH_3), 3.39 (s, OCH_3), 3.59 (q, $J = 7.2\text{ Hz}$, NCH_2CH_3), 3.67 (t, $J = 4.8\text{ Hz}$, $\text{OCH}_2\text{CH}_2\text{N}$), 3.91 (s, $\text{OCH}_2\text{CH}_2\text{N}$).

^{19}F NMR (376.05 MHz/acetone- d_6 , δ ppm relative to external CCl_3F): -83.0 (s, CF_3), 135.8 (q, $^2J_{\text{BF}} = 20.3\text{Hz}$, CF_2), -152.8 (q, $^1J_{\text{BF}} = 40.7\text{ Hz}$, BF_3).

^{11}B NMR (128.15 MHz/acetone- d_6 , δ ppm relative to external $\text{BF}_3\cdot\text{Et}_2\text{O}$): 0.149 (qt, $^1J_{\text{BF}} = 40.8\text{ Hz}$, $^2J_{\text{BF}} = 19.1\text{ Hz}$).

Anal. Calc. for $\text{C}_{10}\text{H}_{20}\text{BF}_8\text{NO}$: C, 36.1; H, 6.1; N, 4.2. Found: C, 36.4; H, 4.2; H, 6.0; N, 4.5%.

[Chemical Formula 3]



5 N_{102.122} [n-C₃F₇BF₃]

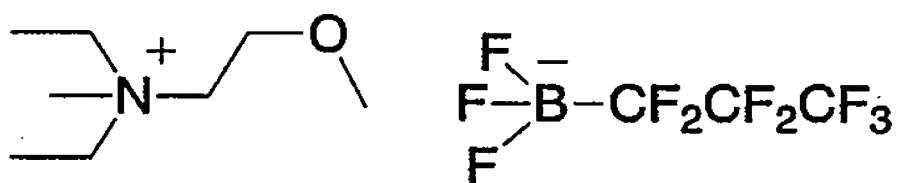
¹H NMR (399.65 MHz/acetone-d₆, δ ppm relative to internal TMS): 1.41 (t, *J* = 7.3 Hz, NCH₂CH₃), 3.20 (s, NCH₃), 3.38 (s, OCH₃), 3.59 (q, *J* = 7.2 Hz, NCH₂CH₃), 3.67 (t, *J* = 4.8 Hz, OCH₂CH₂N), 3.91 (s, OCH₂CH₂N).

10 ¹⁹F NMR (376.05 MHz/acetone-d₆, δ ppm relative to external CCl₃F): -80.3 (s, CF₃), -127.5 (s, CF₃CF₂), 133.7 (s, CF₂B), -152.3 (q, ¹*J*_{BF} = 38.7 Hz, BF₃).

¹¹B NMR (128.15 MHz/acetone-d₆, δ ppm relative to external BF₃·Et₂O): 0.246 (qt, ¹*J*_{BF} = 40.6 Hz, ²*J*_{BF} = 19.0 Hz).

15 Anal. Calc. for C₁₁H₂₀BF₁₀NO: C, 34.5; H, 5.3; N, 3.7. Found: C, 34.7; H, 5.2; N, 3.7%.

[Chemical Formula 4]



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N_{102.122} [n-C₄F₉BF₃]

¹H NMR (399.65 MHz/acetone-d₆, δ ppm relative to internal TMS): 1.41 (m, NCH₂CH₃), 3.21 (m, NCH₃), 3.38 (m, OCH₃), 3.60 (q, *J* = 7.2 Hz, NCH₂CH₃), 3.67 (t, *J* = 4.8 Hz, OCH₂CH₂N), 3.91 (s, OCH₂CH₂N).

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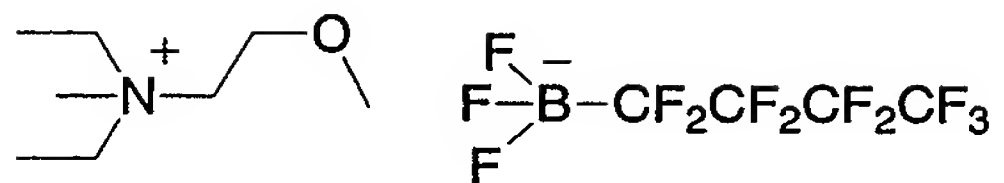
¹⁹F NMR (376.05 MHz/acetone-d₆, δ ppm relative to external CCl₃F): -80.9 (s, CF₃), -123.8 (s, CF₃CF₂), 125.8 (s, CF₃CF₂CF₂), 133.1 (s, CF₂B), -152.3 (q, ¹*J*_{BF} = 38.7 Hz, BF₃).

¹¹B NMR (128.15 MHz/acetone-d₆, δ ppm relative to external BF₃·Et₂O): 0.233 (qt, ¹*J*_{BF} = 40.3 Hz, ²*J*_{BF} = 19.0 Hz).

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Anal. Calc. for C₁₂H₂₀BF₁₂NO: C, 33.3; H, 4.7; N, 3.2. Found: C, 33.6; H, 4.6; N, 3.4%.

[Chemical Formula 5]



N_{102.111}[C₂F₅BF₃]

5 Elemental Analysis Calc. (Found): C, 31.5 (31.2); H, 5.3 (5.2); N, 4.6 (4.6)%.

¹H NMR: 3.37 (s, 3 × 3H), 3.40 (s, 3H), 3.76 (s, 2H), 3.94 (s, 2H).

¹⁹F NMR: -83.0 (s, CF₃), -135.8 (q, ²J_{BF} = 19.3 Hz, CF₂),
10 -153.0 (q, ¹J_{BF} = 39.6 Hz, BF₃).

N_{102.112}[C₂F₅BF₃]

Elemental Analysis Calc. (Found): C, 33.9 (33.7); H, 5.7 (5.6); N, 4.4 (4.3)%.

¹H NMR: 1.45 (t, J = 7.2 Hz, 3H), 3.28 (s, 2 × 3H), 3.39
15 (s, 3H), 3.64 (q, J = 7.2 Hz, 2H), 3.71 (t, J = 4.8 Hz, 2H), 3.92 (s, 2H).

¹⁹F NMR: -83.0 (s, CF₃), -135.8 (q, ²J_{BF} = 19.3 Hz, CF₂),
-152.7 (q, ¹J_{BF} = 40.7 Hz, BF₃).

N_{102.122}[C₂F₅BF₃]

20 Elemental Analysis Calc. (Found): C, 36.1 (35.8); H, 6.1 (5.9); N, 4.2 (4.1)%.

¹H NMR: 1.41 (t, J = 7.2 Hz, 2 × 3H), 3.19 (s, 3H), 3.39
(s, 3H), 3.59 (q, J = 7.2 Hz, 2 × 2H), 3.67 (t, J = 4.8 Hz, 2H),
3.91 (s, 2H).

¹⁹F NMR: -83.0 (s, CF₃), -135.8 (q, ²J_{BF} = 20.3 Hz, CF₂),
25 -152.8 (q, ¹J_{BF} = 40.7 Hz, BF₃).

N_{102.222}[C₂F₅BF₃]

Elemental Analysis Calc. (Found): C, 38.1 (38.1); H, 6.4 (6.4); N, 4.0 (4.0)%.

¹H NMR: 1.37 (t, J = 7.2 Hz, 3 × 3H), 3.38 (s, 3H), 3.56
30 (q, J = 7.2 Hz, 3 × 2H), 3.63 (t, J = 4.8 Hz, 2H), 3.87 (s, 2H).

¹⁹F NMR: -83.0 (s, CF₃), -135.8 (q, ²J_{BF} = 19.4 Hz, CF₂),
-153.0 (q, ¹J_{BF} = 39.7 Hz, BF₃).

DMI[CF₃BF₃]

Elemental Analysis Anal. Calc. (Found): C, 30.8 (30.5); H, 3.9 (4.0); N, 12.0 (11.9)%.

^1H NMR: 4.02 (s, $2 \times 3\text{H}$, NCH_3), 7.66 (m, 2H, N-CH=CH-N), 8.89 (s, 1H, N-CH-N).

5 PMI[CF_3BF_3]

Elemental Analysis Calc. (Found): C, 36.7 (36.5); H, 5.0 (5.1); N, 10.7 (10.8)%.

^1H NMR: 0.96 (t, $J = 7.2$ Hz, 3H, CCH_3), 1.98 (m, 2H, CH_3CH_2-), 4.06 (s, 3H, N-CH_3), 4.32 (q, $J = 7.3$ Hz, 2H, NCH_2-), 7.71 and 7.75 (s, 2H, N-CH=CH-N), 8.99 (s, 1H, N-CH-N).

BMI[CF_3BF_3]

Elemental Analysis Calc. (Found): C, 39.2 (38.9); H, 5.5 (5.8); N, 10.2 (10.2)%.

^1H NMR: 0.95 (t, $J = 7.2$ Hz, 3H, CCH_3), 1.40 (m, 2H, CH_3CH_2-), 1.93 (m, 2H, CH_3CCH_2-), 4.04 (s, NCH_3), 4.35 (q, $J = 7.3$ Hz, 2H, NCH_2-), 7.68 and 7.74 (s, 2H, N-CH=CH-N), 8.95 (s, 1H, N-CH-N).

HMI[CF_3BF_3]

Elemental Analysis Calc. (Found): C, 43.5 (43.2); H, 6.3 (6.0); N, 9.2 (9.3)%.

^1H NMR: 0.87 (t, $J = 7.0$ Hz, 3H, CCH_3), 1.34 (m, $3 \times 2\text{H}$, $\text{CH}_3(\text{CH}_2)_3-$), 1.95 (m, 2H, NCH_2CH_2-), 4.04 (s, 3H, NCH_3), 4.35 (t, $J = 7.2$ Hz, 2H, NCH_2-), 7.69 and 7.75 (s, 2H, N-CH=CH-N), 8.97 (s, 1H, N-CH-N).

25 In Tables 3 to 5, d = density at 25 °C; T_g = glass transition temperature (on heating); T_c = crystallization temperature (on heating); T_m = melting point (on heating); η = viscosity at 25 °C; κ = conductivity at 25 °C; and Nd = not detected.

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[Table 3]

Physicochemical Properties of Ionic liquids Containing
Ammonium Cations

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salt	T _g /°C	T _c /°C	T _m /°C	T _d /°C	η/ m Pas	κ/ m Scm ⁻¹
N _{102.222} [BF ₄]	Nd	Nd	56	372	Solid	Solid
N _{102.122} [BF ₄]	-95	-51	8	372	426	1.3
N _{102.112} [BF ₄]	-97	-26	4	377	335	1.7
N _{102.111} [BF ₄]	Nd	Nd	54	376	Solid	Solid
N ₁₂₂₄ [BF ₄]	Nd	Nd	165	392	Solid	Solid
N _{101.112} [CF ₃ BF ₃]	Nd	Nd	30	173	Solid	Solid
N _{102.122} [CF ₃ BF ₃]	Nd	Nd	-22	174	108	3.0
N _{102.222} [CF ₃ BF ₃]	Nd	Nd	10	210	151	2.0
N _{102.112} [CF ₃ BF ₃]	Nd	Nd	8	163	97	2.5
Py _{102.1} [CF ₃ BF ₃]	Nd	Nd	-15	232	87	4.3
Pi _{102.1} [CF ₃ BF ₃]	Nd	Nd	-16	234	203	1.8
N ₁₂₂₄ [CF ₃ BF ₃]	Nd	Nd	-3	212	210	2.1

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[Table 4]

salt	T _g /°C	T _c /°C	T _m /°C	T _d /°C	η/ m Pas	κ/ m Scm ⁻¹
N _{102.122} [C ₂ F ₅ BF ₃]	-113	Nd	Nd	322	68	3.2
N _{102.122} [n-C ₃ F ₇ BF ₃]	-112	Nd	Nd	275	88	1.9
N _{102.122} [n-C ₄ F ₉ BF ₃]	-108	Nd	Nd	287	118	1.3
N _{102.111} [C ₂ F ₅ BF ₃]	Nd	Nd	30	326	Solid	Solid
N _{102.112} [C ₂ F ₅ BF ₃]	-117	-76	-33	307	58	3.8
N _{102.222} [C ₂ F ₅ BF ₃]	-98	-63	3	345	87	2.4
N _{101.112} [C ₂ F ₅ BF ₃]	Nd	Nd	11	287	44	5.4
Py _{101.1} [C ₂ F ₅ BF ₃]	Nd	Nd	26	299	37	6.8
Py _{102.1} [C ₂ F ₅ BF ₃]	Nd	Nd	-3	289	52	4.5
Pi _{102.1} [C ₂ F ₅ BF ₃]	Nd	Nd	-17	301	112	2.2
N ₁₂₂₄ [C ₂ F ₅ BF ₃]	Nd	Nd	15	320	104	2.3
N _{102.112} [n-C ₃ F ₇ BF ₃]	-113	Nd	Nd	291	70	2.6
N _{102.222} [n-C ₃ F ₇ BF ₃]	Nd	Nd	6	351	91	1.8
N _{102.111} [n-C ₃ F ₇ BF ₃]	Nd	Nd	23	284	76	2.5
Py _{102.1} [n-C ₃ F ₇ BF ₃]	Nd	Nd	5	283	62	3.3
Pi _{102.1} [n-C ₃ F ₇ BF ₃]	Nd	Nd	21	297	187	0.93
N _{102.222} [n-C ₄ F ₉ BF ₃]	Nd	Nd	11	305	135	1.1
N _{102.112} [n-C ₄ F ₉ BF ₃]	-110	-56	-28	283	102	1.5
Py _{102.1} [n-C ₄ F ₉ BF ₃]	-100	-63	-13	284	84	2.1
Pi _{102.1} [n-C ₄ F ₉ BF ₃]	-91	-62	-7	298	131	1.5
Py ₁₁ [C ₂ F ₅ BF ₃]	Nd	Nd	>150	325	Solid	Solid
Py ₁₂ [C ₂ F ₅ BF ₃]	Nd	Nd	>150	307	Solid	Solid
Py ₁₃ [C ₂ F ₅ BF ₃]	Nd	Nd	63	312	Solid	Solid
Py ₁₄ [C ₂ F ₅ BF ₃]	Nd	Nd	22	311	71	3.5
Py ₁₅ [C ₂ F ₅ BF ₃]	Nd	Nd	36	307	Solid	Solid
Py ₁₆ [C ₂ F ₅ BF ₃]	Nd	Nd	58	307	Solid	Solid
Py ₁₇ [C ₂ F ₅ BF ₃]	Nd	Nd	52	311	Solid	Solid
Py _{1.101} [C ₂ F ₅ BF ₃]	Nd	Nd	26	299	37	6.8
Py _{1.102} [C ₂ F ₅ BF ₃]	Nd	Nd	-3	289	52	4.5
Py _{1.202} [C ₂ F ₅ BF ₃]	-108	Nd	-6	290	49	3.7
Py _{1.10202} [C ₂ F ₅ BF ₃]	-98	Nd	Nd	297	54	3.0

[Table 5]

Ionic liquids Containing Morpholinium Cations

salt	Tg /°C	Tc /°C	Tm /°C	Td /°C	η / m Pas	κ / m Scm ⁻¹
Mor ₁₄ [CF ₃ BF ₃]	-73	Nd	Nd	181	1035	0.37
Mor ₁₄ [C ₂ F ₅ BF ₃]	-72	Nd	Nd	303	466	0.51
Mor ₁₄ [n-C ₃ F ₇ BF ₃]	Nd	Nd	69	317	Solid	Solid
Mor ₁₄ [n-C ₄ F ₉ BF ₃]	Nd	Nd	77	300	Solid	Solid
Mor ₁₄ [BF ₄]	Nd	Nd	66	382	Solid	Solid
Mor _{1.102} [CF ₃ BF ₃]	Nd	-42	0	232	471	0.68
Mor _{1.102} [C ₂ F ₅ BF ₃]	-78	Nd	Nd	306	260	0.85
Mor _{1.102} [n-C ₃ F ₇ BF ₃]	-75	Nd	Nd	302	377	0.51
Mor _{1.102} [n-C ₄ F ₉ BF ₃]	Nd	Nd	13 0	291	Solid	Solid
Mor _{1.102} [BF ₄]	-58	2.1	85	365	Solid	Solid

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Test Example 1: Measurement of Physical Values

Fig. 1 shows a linear sweep voltammogram of the [C₂F₅BF₃] salt.

Fig. 2 shows the results of linear sweep voltammetry performed on N₁₀₂₁₁₂[CF₃BF₃] and EMI [CF₃BF₃] at room temperature in a glove box (O₂ and water < 5 ppm) filled with argon for the evaluation of electrochemical stability (working electrode: glassy carbon; counter electrode: platinum; reference electrode: a platinum wire immersed in iodine redox-containing EMI-TFSI. Calculated using the redox potential of ferrocene in the ionic liquid as an internal standard. Measured by ALS, model 660 electrochemical analyzer).

The results of Fig. 2 show that the reduction and oxidization potentials of N₁₀₂₁₁₂[CF₃BF₃] shifted to more negative and positive potentials, respectively, than those of EMI[CF₃BF₃]; therefore the electrochemical stability of N₁₀₂₁₁₂[CF₃BF₃] is enhanced.

The results presented above demonstrate that the ionic liquid N₁₀₂₁₁₂[CF₃BF₃] of the present invention has a high conductivity and low melting point, hence exhibiting superior

properties as a solvent for electrochemical devices and organic reactions.

Comparative Examples 1 through 4

Four compounds shown below which are disclosed in the specification of Patent Publication 3 (Japanese Unexamined Patent Publication 2002-63947) and in Table 1 were synthesized, and the melting points of these compounds were measured. The results are shown below:

[Table 6]

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Salt	Melting point
Triethylmethyammonium (TEMA) [CF ₃ BF ₃]	181 °C
Tetraethylammonium [CF ₃ BF ₃]	237 °C (decomposition)
N,N'-dimethylpyrrolidinium [CF ₃ BF ₃]	m. p.: 325 °C (decomposition)
N-methyl-N'-ethylpyrrolidinium [CF ₃ BF ₃]	m. p.: 280 °C (decomposition)

A comparison with the results above show that the melting points of ionic liquids greatly vary with slight differences in the structure of the ammonium cation.